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H04L 29/06

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H4P PPEB

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(54) Abstract Title
Lightweight secure communication tunnelling over the internet

(57) A lightweight secure tunnelling protocol or LSTP permits communicating across one or more firewalls by using a middle server or proxy. Three proxies are used to establish an end-to-end connection that navigates through the firewalls. In a typical configuration, a server 211 is behind a first firewall 23 and a client 222 behind a second firewall 25 are interconnected by an untrusted network 12 (e.g., the Internet) between the firewalls. A first inside firewall SOCKS-aware server-side end proxy 213 connects to the server 211 inside the first firewall 23. A second inside firewall SOCKS-aware client-side end Proxy 223 is connected to by the client 222 inside the second firewall 25. Both server-side and client-side end proxies 213, 223 can address a third proxy (called a middle proxy) 26 outside the two firewalls 23, 25.

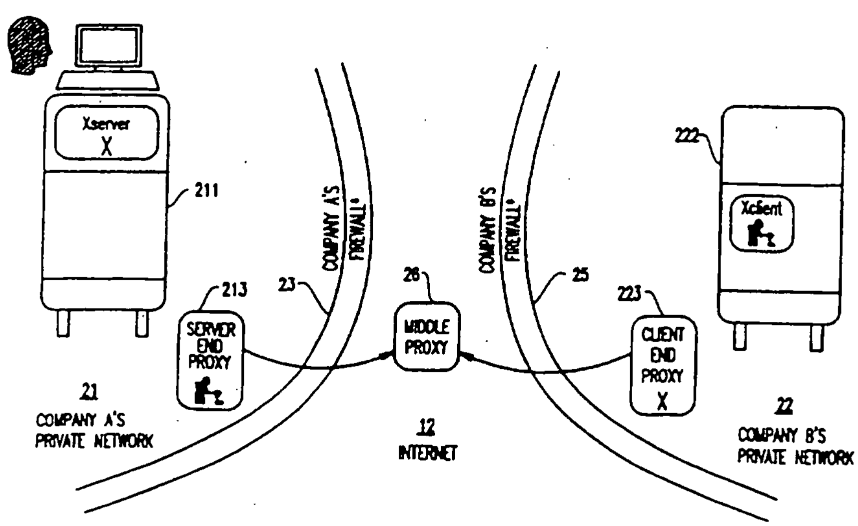

FIG.4

GB 2 323 757 A

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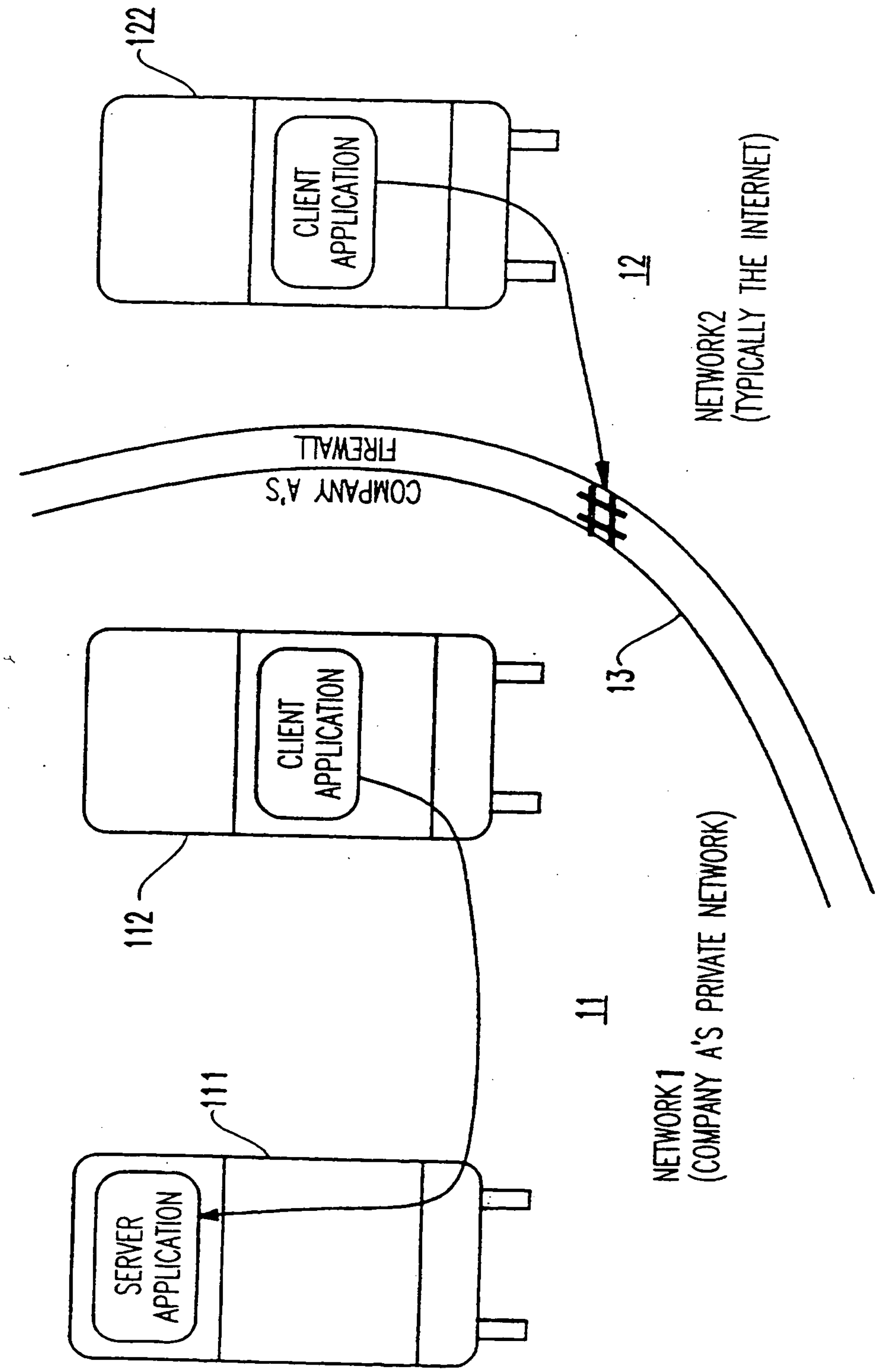

122
CLIENT APPLICATION
12
NETWORK2 (TYPICALLY THE INTERNET)
COMPANY A'S FIREWALL
13
CLIENT APPLICATION
112
11
NETWORK1 (COMPANY A'S PRIVATE NETWORK)
111
SERVER APPLICATION

FIG.1

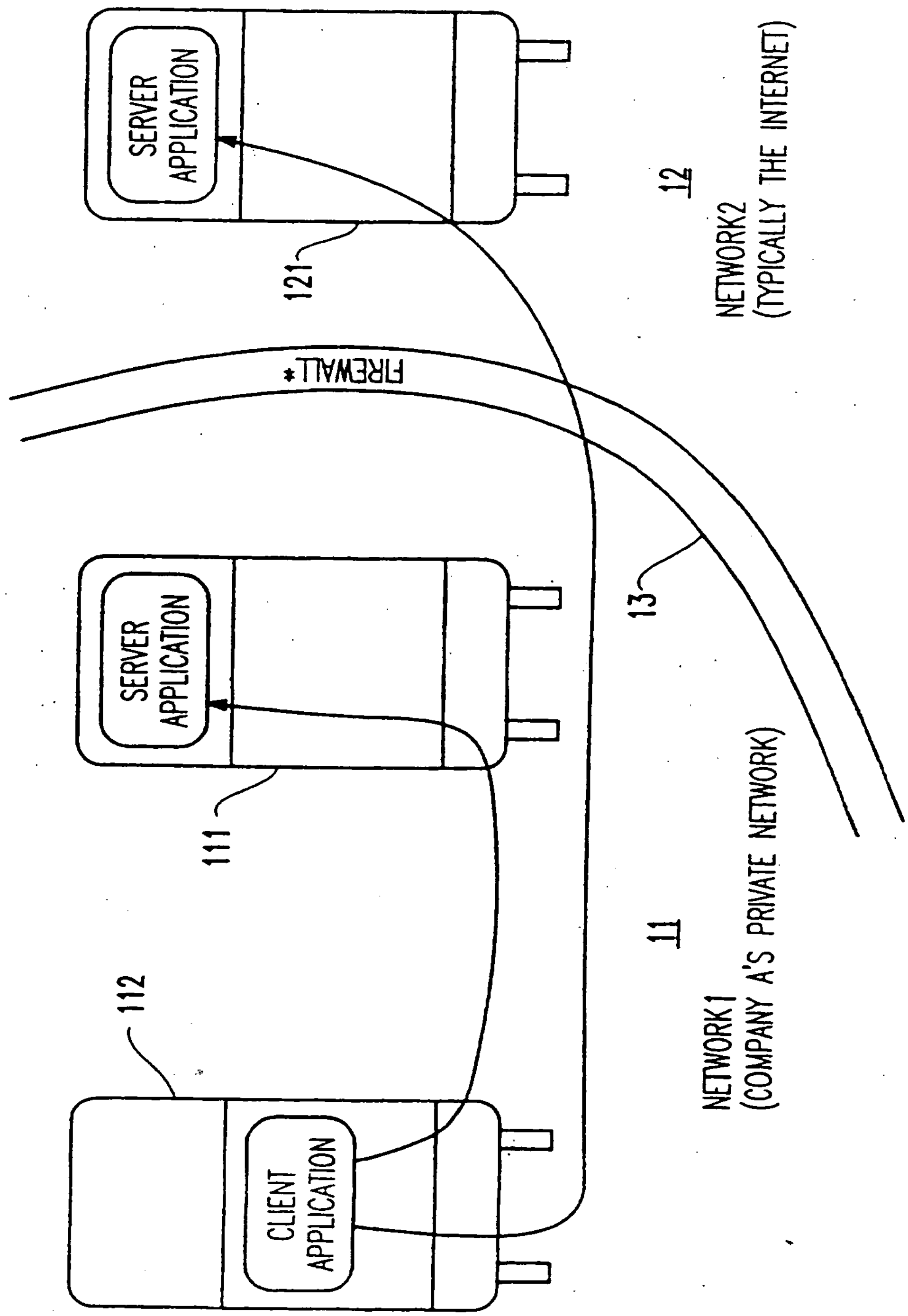

SERVER APPLICATION
121
NETWORK2 (TYPICALLY THE INTERNET)
12
FIREWALL*
13
SERVER APPLICATION
111
CLIENT APPLICATION
112
11
NETWORK1 (COMPANY A'S PRIVATE NETWORK)

FIG.2

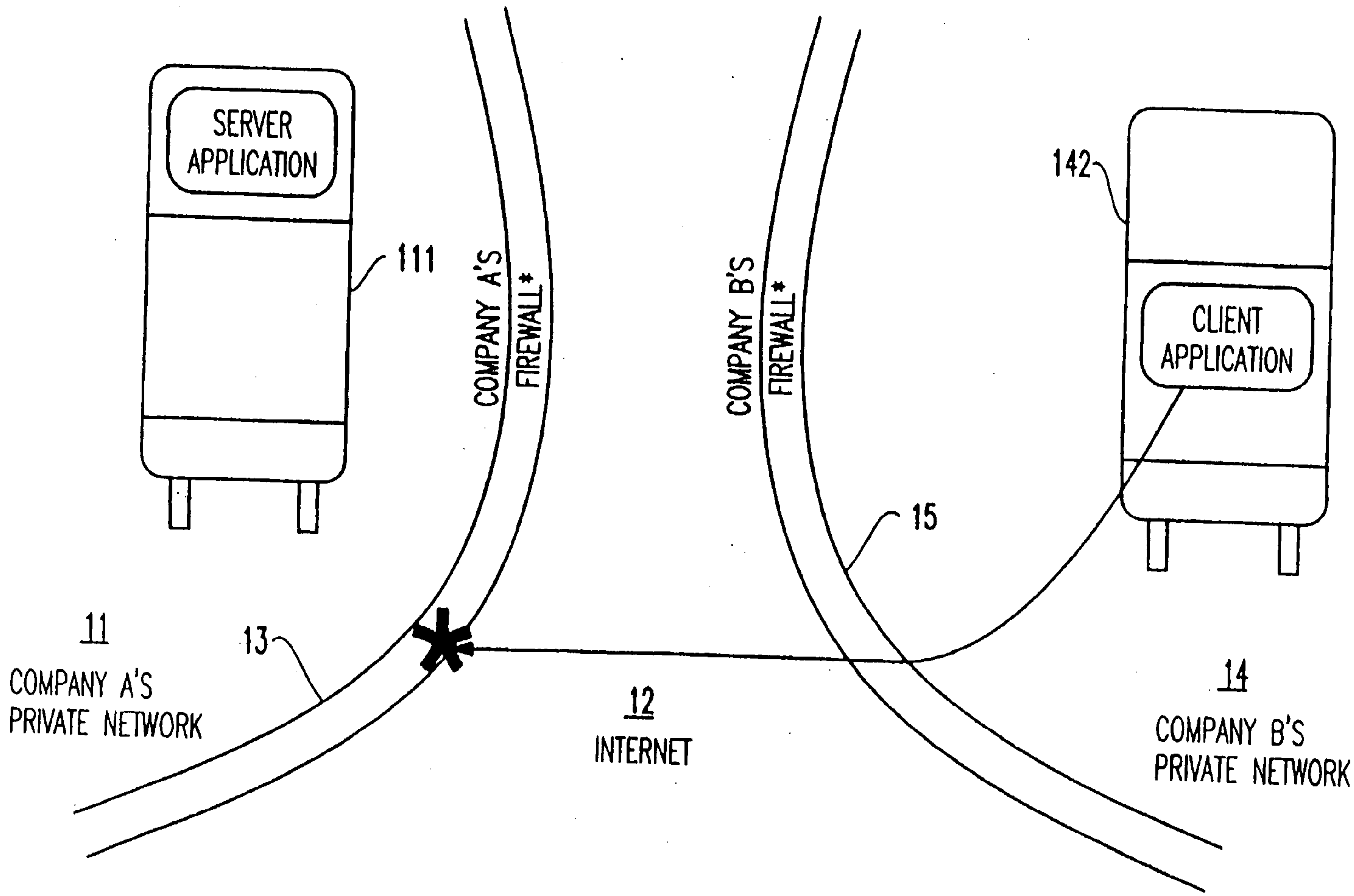
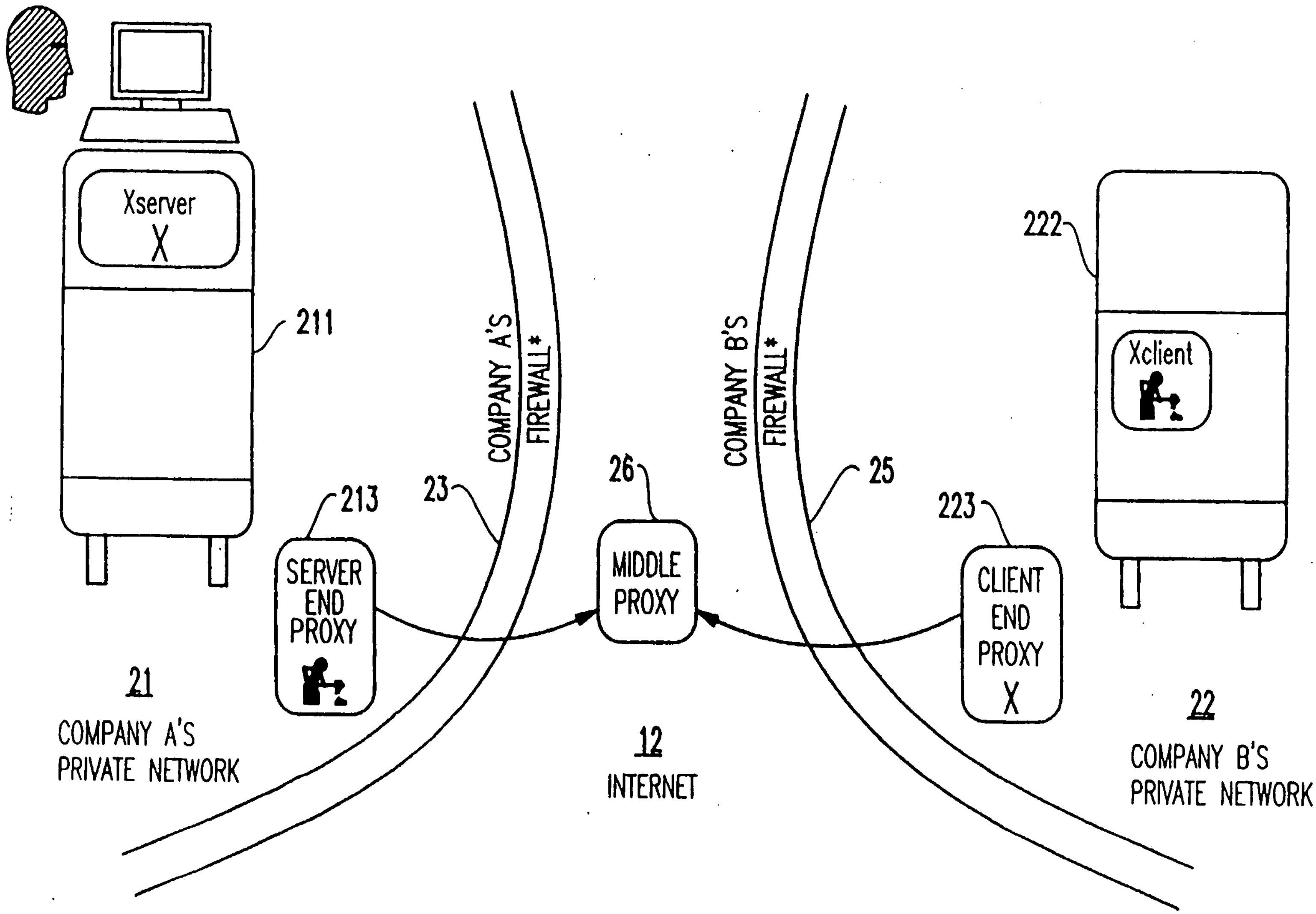

SERVER
APPLICATION
111
COMPANY A'S
FIREWALL*
COMPANY B'S
FIREWALL*
142
CLIENT
APPLICATION
15
11
COMPANY A'S
PRIVATE NETWORK
13
12
INTERNET
14
COMPANY B'S
PRIVATE NETWORK

FIG.3



Xserver
X
211
213
SERVER
END
PROXY
21
COMPANY A'S
PRIVATE NETWORK
23
COMPANY A'S
FIREWALL*
26
MIDDLE
PROXY
12
INTERNET
COMPANY B'S
FIREWALL*
25
223
CLIENT
END
PROXY
X
222
Xclient
22
COMPANY B'S
PRIVATE NETWORK

FIG.4

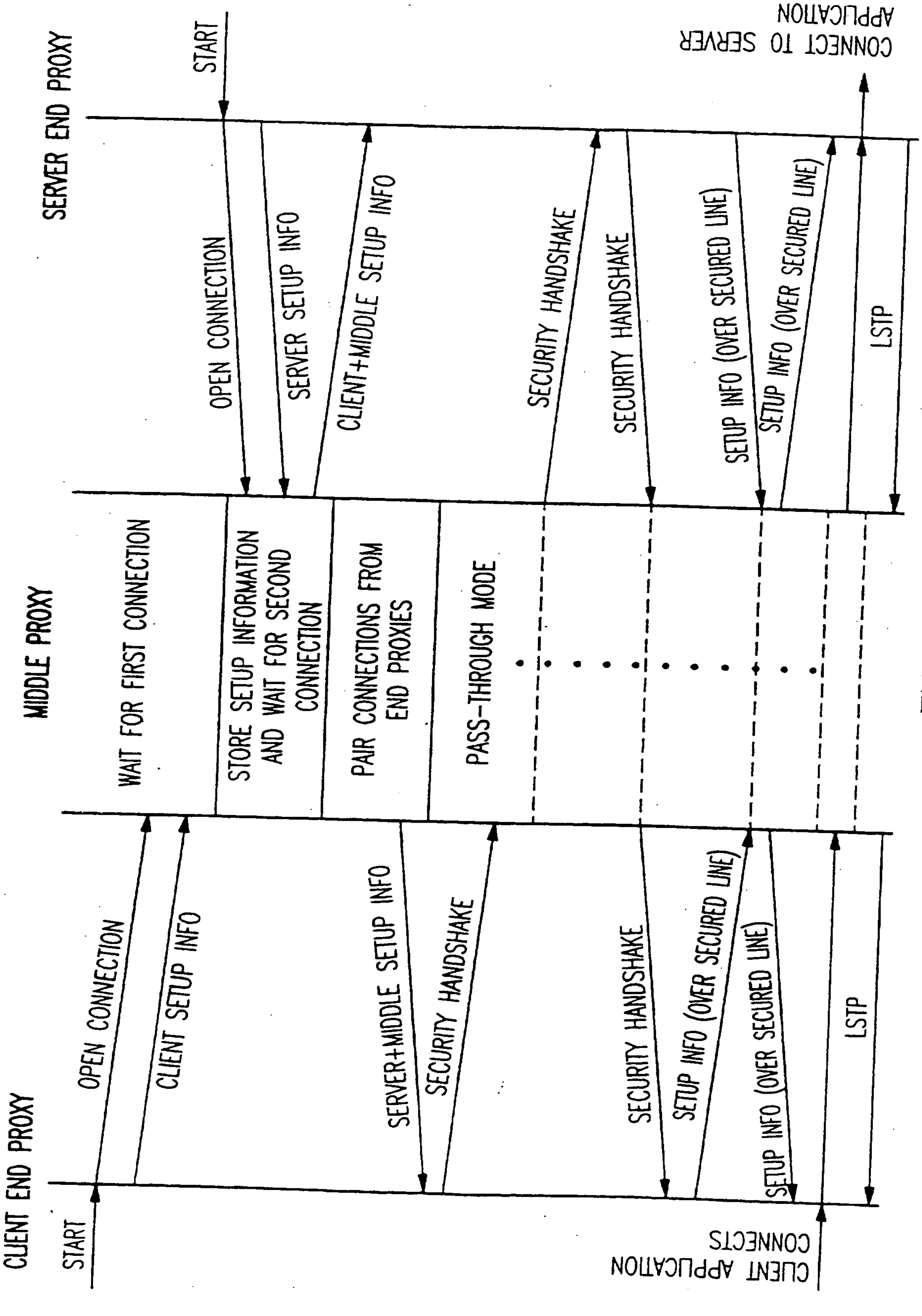

SERVER END PROXY
MIDDLE PROXY
CLIENT END PROXY
START
OPEN CONNECTION
SERVER SETUP INFO
CLIENT+MIDDLE SETUP INFO
SECURITY HANDSHAKE
SECURITY HANDSHAKE
SETUP INFO (OVER SECURED LINE)
SETUP INFO (OVER SECURED LINE)
LSTP
CONNECT TO SERVER APPLICATION
WAIT FOR FIRST CONNECTION
STORE SETUP INFORMATION AND WAIT FOR SECOND CONNECTION
PAIR CONNECTIONS FROM END PROXIES
PASS-THROUGH MODE
START
OPEN CONNECTION
CLIENT SETUP INFO
SERVER+MIDDLE SETUP INFO
SECURITY HANDSHAKE
SECURITY HANDSHAKE
SETUP INFO (OVER SECURED LINE)
SETUP INFO (OVER SECURED LINE)
LSTP
CLIENT APPLICATION CONNECTS

FIG.5

LSTP MESSAGES	GENERAL PURPOSE OF MESSAGES
COMMONUNIQUE_INFO TOPOLOGY_EXCHANGE PROPERTY_EXCHANGE	MANAGE TUNNEL SETUP AND ADMINISTRATION
CONNECTION_REQUEST CONNECTION_ACK CONNECTION_NACK SERVICE_BEGIN_REQUEST SERVICE_BEGIN_ACK SERVICE_BEGIN_NACK	MANAGE RESOURCES OF AN EXISTING TUNNEL AS REQUIRED BY APPLICATIONS USING THE TUNNEL
SERVICE_DATA	TRANSPORT APPLICATION DATA BETWEEN END PROXIES
SERVICE_DATA_PAUSE SERVICE_DATA_RESUME	MANAGE APPLICATION DATA - FLOW CONTROL
SERVICE_FREE_REQUEST SERVICE_FREE_RESPONSE SHUTDOWN	MANAGE CLEANUP OF TUNNEL RESOURCES NO LONGER NEEDED BY AN APPLICATION
ERROR	MANAGE ERROR CONDITIONS

FIG.6

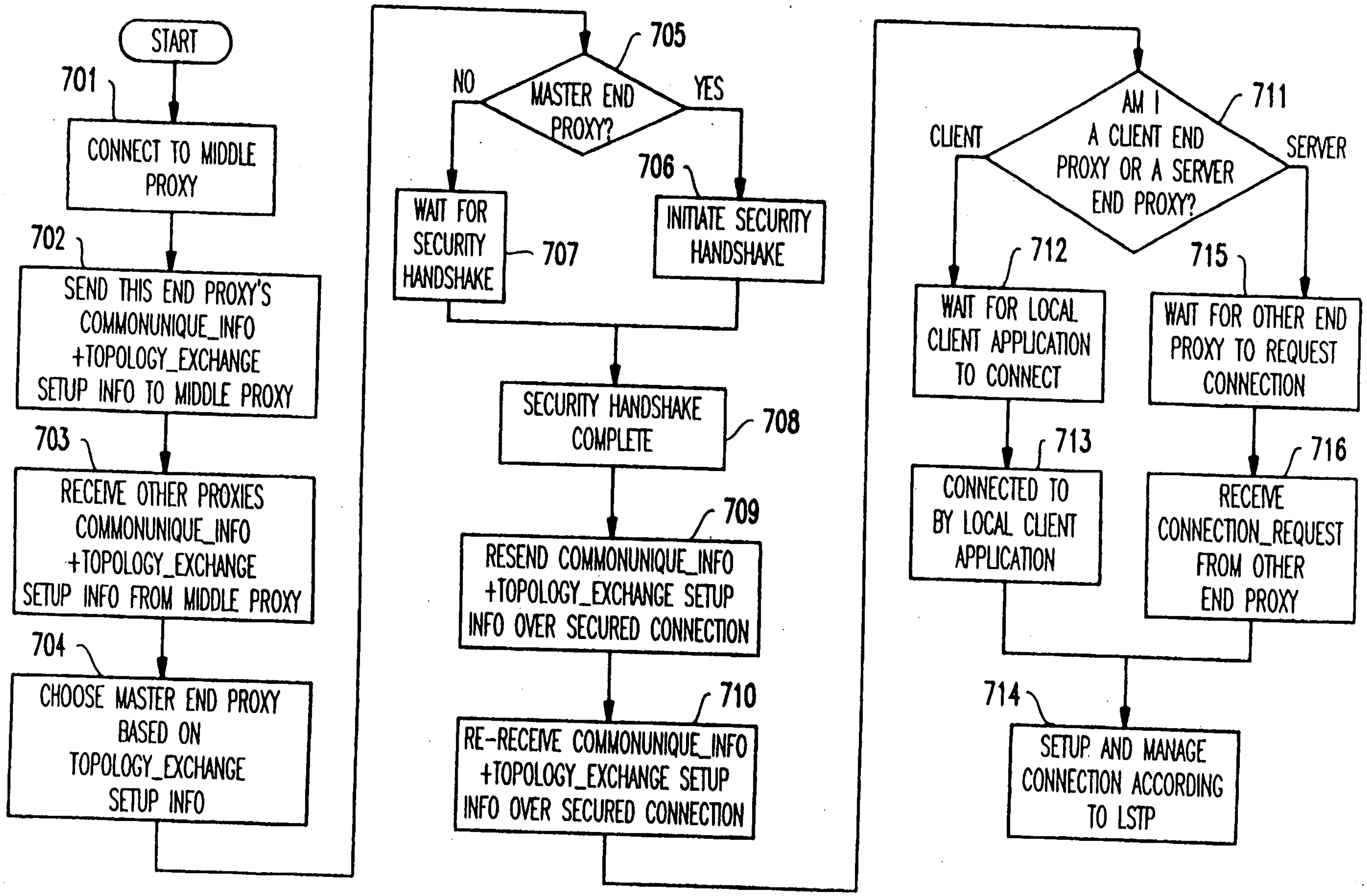

START
701
CONNECT TO MIDDLE PROXY
702
SEND THIS END PROXY'S COMMONUNIQUE_INFO +TOPOLOGY_EXCHANGE SETUP INFO TO MIDDLE PROXY
703
RECEIVE OTHER PROXIES COMMONUNIQUE_INFO +TOPOLOGY_EXCHANGE SETUP INFO FROM MIDDLE PROXY
704
CHOOSE MASTER END PROXY BASED ON TOPOLOGY_EXCHANGE SETUP INFO
705
MASTER END PROXY?
NO
YES
706
INITIATE SECURITY HANDSHAKE
707
WAIT FOR SECURITY HANDSHAKE
708
SECURITY HANDSHAKE COMPLETE
709
RESEND COMMONUNIQUE_INFO +TOPOLOGY_EXCHANGE SETUP INFO OVER SECURED CONNECTION
710
RE-RECEIVE COMMONUNIQUE_INFO +TOPOLOGY_EXCHANGE SETUP INFO OVER SECURED CONNECTION
711
AM I A CLIENT END PROXY OR A SERVER END PROXY?
CLIENT
SERVER
712
WAIT FOR LOCAL CLIENT APPLICATION TO CONNECT
713
CONNECTED TO BY LOCAL CLIENT APPLICATION
715
WAIT FOR OTHER END PROXY TO REQUEST CONNECTION
716
RECEIVE CONNECTION_REQUEST FROM OTHER END PROXY
714
SETUP AND MANAGE CONNECTION ACCORDING TO LSTP

FIG.7

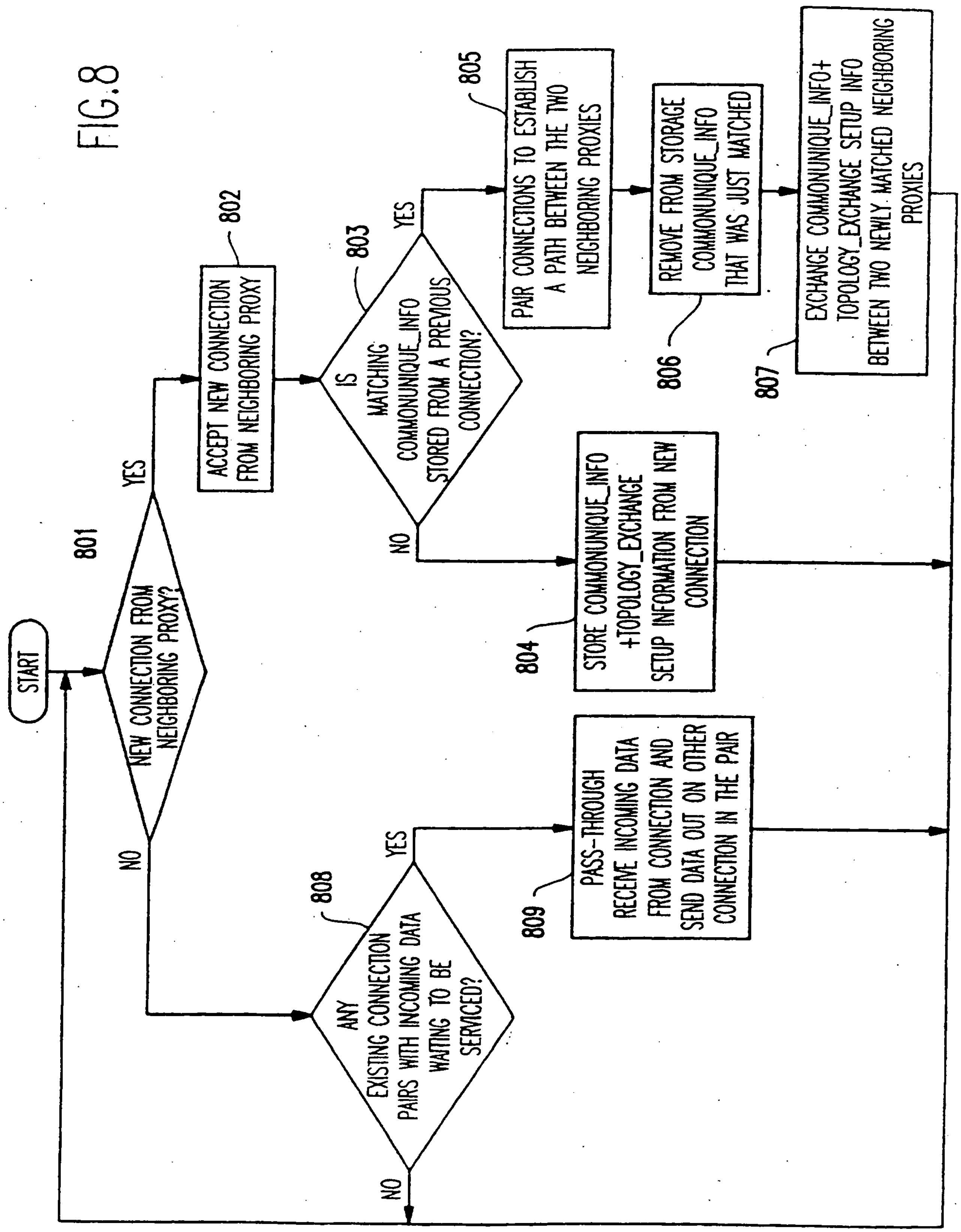
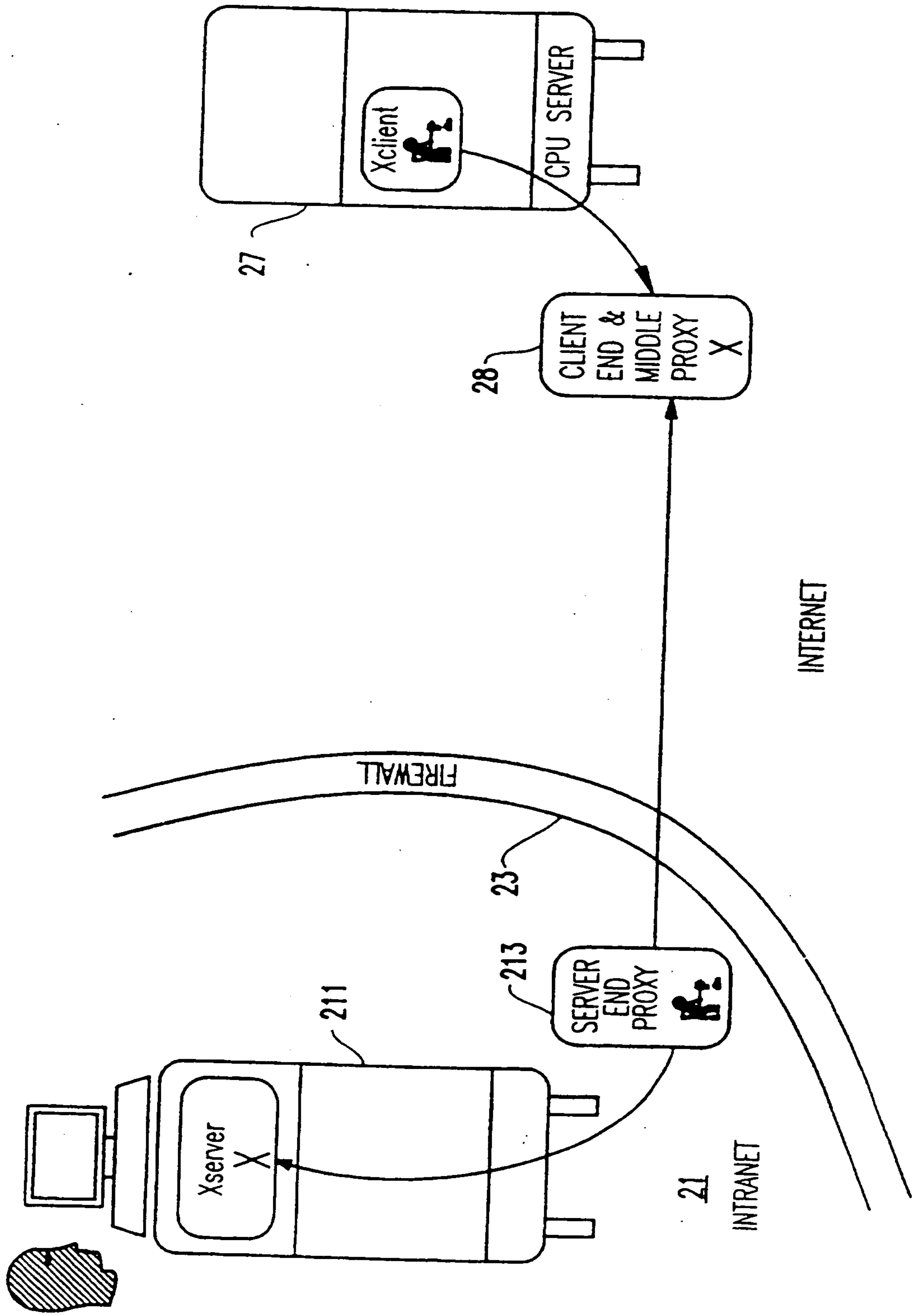

START
801
NEW CONNECTION FROM NEIGHBORING PROXY?
YES
NO
802
ACCEPT NEW CONNECTION FROM NEIGHBORING PROXY
803
IS MATCHING COMMONUNIQUE_INFO STORED FROM A PREVIOUS CONNECTION?
YES
NO
804
STORE COMMONUNIQUE_INFO +TOPOLOGY_EXCHANGE SETUP INFORMATION FROM NEW CONNECTION
805
PAIR CONNECTIONS TO ESTABLISH A PATH BETWEEN THE TWO NEIGHBORING PROXIES
806
REMOVE FROM STORAGE COMMONUNIQUE_INFO THAT WAS JUST MATCHED
807
EXCHANGE COMMONUNIQUE_INFO+ TOPOLOGY_EXCHANGE SETUP INFO BETWEEN TWO NEWLY MATCHED NEIGHBORING PROXIES
808
ANY EXISTING CONNECTION PAIRS WITH INCOMING DATA WAITING TO BE SERVICED?
YES
NO
809
PASS-THROUGH RECEIVE INCOMING DATA FROM CONNECTION AND SEND DATA OUT ON OTHER CONNECTION IN THE PAIR

FIG.8



Xclient
CPU SERVER
27
CLIENT END & MIDDLE PROXY X
28
INTERNET
FIREWALL
23
SERVER END PROXY
213
211
Xserver X
21
INTRANET

FIG.9

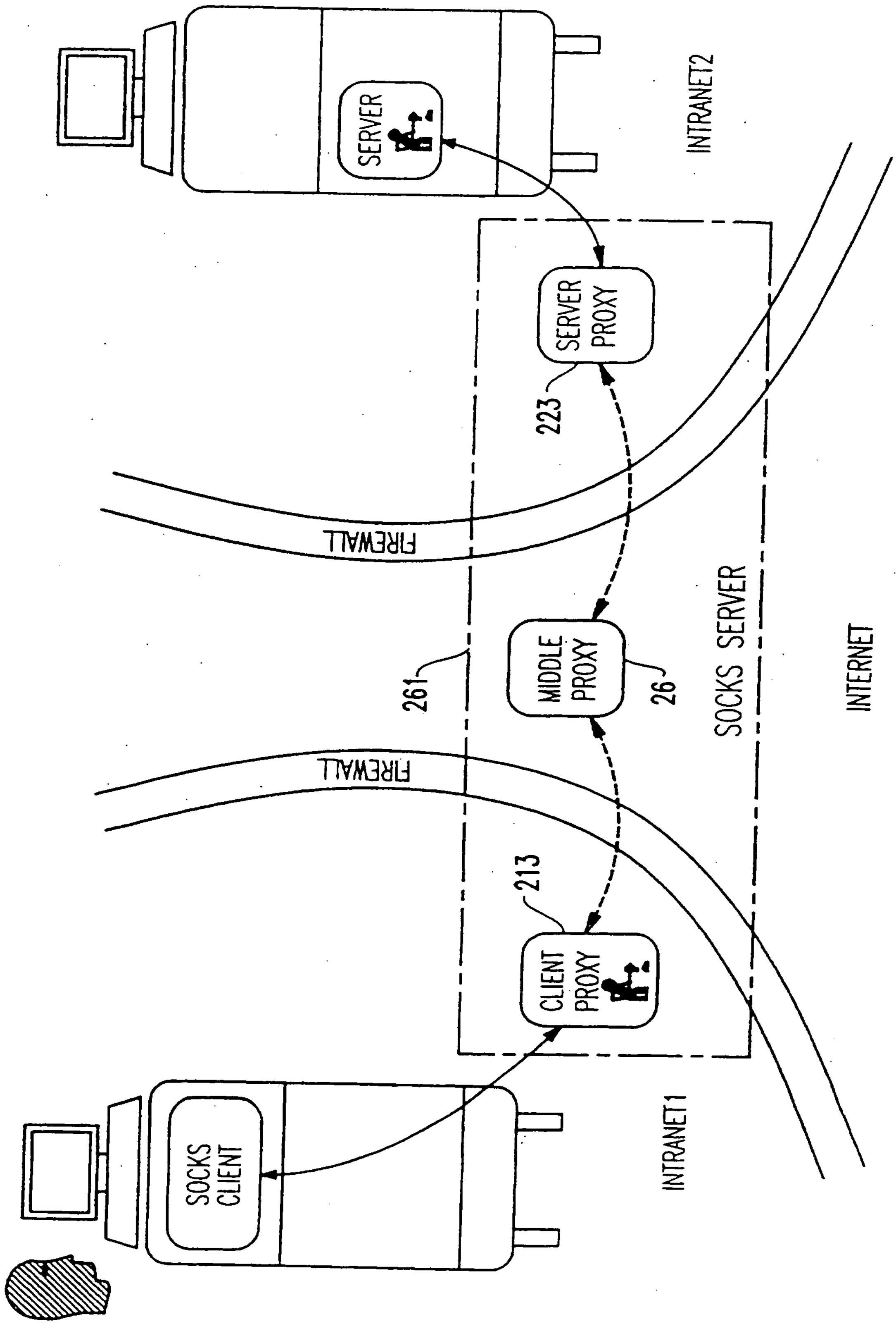

SOCKS CLIENT
INTRANET1
CLIENT PROXY
213
FIREWALL
261
MIDDLE PROXY
26
SOCKS SERVER
INTERNET
FIREWALL
223
SERVER PROXY
SERVER
INTRANET2

FIG.10

2323757

METHOD AND APPARATUS FOR LIGHTWEIGHT SECURE COMMUNICATION TUNNELLING OVER THE INTERNET

Field of the Invention

The present invention generally relates to packet switched network communications and, more particularly, a method and apparatus which provides the ability to allow a TCP/IP client situated outside of an organization's "firewall" to address a server inside the same firewall, even when the firewall is configured to not allow outside clients to address the inside server.

Background Description

The Internet is a collection of networks throughout the world which facilitates the sharing of resources among participating organizations, including government agencies, educational institutions and private corporations. These networks use the Transmission Control Protocol/Internet Protocol (TCP/IP) protocol suite and share a common address space. Thus, computers on the Internet use compatible communications standards and share the ability to contact each other and exchange data. Users of the Internet communicate mainly via electronic mail (e-mail), via Telnet, a process that allows users to log in to a remote host, and via implementations of the File Transfer Protocol (FTP), a protocol that allows them to transfer information on a remote host to their local site.

Security is a major concern when connecting a network, such as a local area network (LAN) to the Internet. One of the more important concerns is intruders attempting to gain access to local hosts. A common method for preventing these types of intrusions is to install a so-called "firewall" which is a secure single point of attachment to the Internet. This single point of attachment takes the form of a firewall host which allows only certain traffic to pass through as specified by the firewall administrator. In a typical firewall host implementation, a user wanting to transfer a file on a host in the LAN to an external host via the Internet first transfers the file to the firewall host and then logs into the firewall and transfer the file to the external host. While this procedure provides a high level of security for a single user, maintaining security becomes difficult as the number of users requiring access to this host increases. For general information on firewalls, see

William R. Cheswick and Steven M. Bellovin, *Firewalls and Internet Security*, Addison-Wesley (1994).

A transport layer proxy architecture, called SOCKS, was created in an attempt to minimize security problems while allowing access by a large number of users. See, for example, David Koblas and Michelle R. Koblas, "SOCKS", *UNIX Security Symposium*, USENIX Association (1992), pp. 77-83, and Ying-Da Lee, "SOCKS: A protocol for TCP proxy across firewalls", http://www.socks.nec.com/socks4.protocol, and M. Leech, M. Ganis, Y. Lee, R. Kuris, D. Koblas, and L. Jones, "SOCKS Protocol Version 5", ftp://ds.internic.net/rfc/rfc1928.txt. In a transport layer proxy architecture, one end system behind the firewall, which is called the client, initiates a session by making a connection to the proxy, which can be thought of as residing on the firewall. The client and proxy use the connection to exchange messages negotiating session setup information such as authentication or proxy request (e.g., the foreign host to connect to for a firewall proxy or the URL (Uniform Resource Locator) to fetch for an HTTP (Hypertext Transfer Protocol) proxy). The proxy then carries out the request, commonly opening a connection to another end-system, typically outside the firewall, which is called the server, as directed by the client. The proxy may exchange session setup information with the server over the connection. After session setup has been completed on both connections, the proxy begins to copy data back and forth between the two connections and does not delete from, add to, or alter the information flowing between the hosts (although it may silently keep a copy of the information, as in the case of HTTP caching proxies).

Often, an employee inside an organization wishes to allow an "outside" client to address his or her "inside" server. In this case, since the employee trusts the outside client, he or she may wish to bypass the controls put in place on the firewall so that the trusted outside client can address the trusted inside server.

Summary of the Invention

It is an object of the present invention to provide a technique which alleviates the above drawbacks.

According to the present invention we provide a packet switched network communications system comprising: a first network including at least one server running a server application; a second network

including at least one client running a client application; a first firewall guarding computer resources of one of the first and second networks and including a software application that enables the first firewall to make connections from inside to outside the first firewall; a server end proxy and a server application that are mutually addressable; a client end proxy and a client application that are mutually addressable; and a middle proxy outside the first firewall and in an untrusted network between the first and second networks, the server end proxy and the client end proxy each making connections to the middle proxy through the first firewall and the middle proxy connecting the connections from the server end proxy and the client end proxy to establish a pass through communication tunnel between the client and the server.

Further, according to the present invention, we provide, in a packet switched network communications system including a first network including at least one server running a server application, a second network including at least one client running a client application, a first firewall guarding computer resources of one of the first and second networks and including a software application that enables the first firewall to make connections from inside to outside the first firewall, a server end proxy addressable by the server application, a client end proxy addressable by the client application, and a middle proxy outside the first firewall and in an untrusted network between the first and second networks, a method of connecting the server end proxy and the client end proxy to the middle proxy through the first firewall and the middle proxy connecting the connections from the server end proxy and the client end proxy to establish a pass through communication tunnel between the client and the server, the method comprising the steps of: starting the middle proxy and waiting for a first connection from an end proxy; starting the client end proxy and opening a connection to the middle proxy by sending client setup information to the middle proxy; storing by the middle proxy the end proxy setup information and then waiting for a second connection; starting the server end proxy and opening a connection to the middle proxy by sending end proxy setup information to the middle proxy; pairing by the middle proxy the connections of the client end proxy and the server end proxy and transmitting server and middle proxy setup information to the client end proxy and client and middle proxy setup information to the server end proxy; and the middle proxy thereafter acting as a pass through between the client end and server end proxies.

According to a preferred embodiment of the invention, there is provided a lightweight secure tunnelling protocol or LSTP which permits communicating across one or more firewalls by using a middle server or proxy. More particularly, the basic system uses three proxies, one middle proxy and two end proxies, to establish an end-to-end connection that navigates through two firewalls. In this configuration, a server behind a first firewall and a client behind a second firewall are interconnected by an untrusted network (e.g., the Internet) between the firewalls. A first inside firewall SOCKS-aware end server-side proxy connects to the server inside the first firewall. The client inside the second firewall connects to a second inside firewall SOCKS-aware client-side end proxy. Both server-side and client-side end proxies can address a third proxy (called a middle proxy) outside the two firewalls. The middle proxy is usually started first, as the other two proxies (server and client end proxies) will initiate the connection to the middle proxy some time after they are started. Since the middle proxy is mutually addressable by both inside end proxies, a complete end-to-end connection between the server and client is established. It is the use of one or more middle proxies together with an appropriate protocol like LSTP that establishes the secure communications link or tunnel across multiple firewalls.

Brief Description of the Drawings

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, in which:

Figure 1 is a block diagram illustrating the typical interaction between a client application and a server application when the server is behind a firewall;

Figure 2 is a block diagram illustrating the typical interaction between a client application and a server application when the client is behind a firewall;

Figure 3 is a block diagram illustrating a typical network configuration between two companies or organizations each having networks behind firewalls;

Figure 4 is a block diagram illustrating the three types of proxies used according to the invention to construct a secure communications channel or tunnel between two companies or organizations;

Figure 5 is a data flow diagram illustrating the interaction between the client, middle and server proxies shown in Figure 4;

Figure 6 is a table summarizing the Lightweight Secure Tunnelling Protocol (LSTP) according to a preferred embodiment of the invention.

Figure 7 is a flow diagram of the process performed on an end proxy;

Figure 8 is a flow diagram of the process performed on a middle proxy;

Figure 9 is a block diagram illustrating an alternative embodiment of the invention where the server proxy connects to the client proxy over a single firewall; and

Figure 10 is a block diagram illustrating another alternative embodiment of the invention in which SOCKS-aware clients allow secure communications over two firewalls.

Detailed Description of Preferred Embodiments of the Invention

Referring now to the drawings, and more particularly to Figure 1, there is shown two networks 11 and 12 separated by a firewall 13. The firewall 13 is used to guard the first network 11 against malicious activity originating from outside the firewall. Network 11 is, in this illustration, Company A's private network, and network 12 is typically the Internet. In this example, network 11 is represented by a server 111 running a server application and a client 112 running a client application. The client application running on client 112 behind the firewall 13 can address the server application running on server 111, but a client application running on client 122 outside the firewall 13 cannot address the server application running on server 111 since this connection is blocked by the firewall. That is, the purpose of the firewall 13 is to guard the computer resources of Company A, in this case, network 11 which may comprise many servers and clients connected together on a local area network (LAN).

In Figure 2, there is shown a similar arrangement except that there is a server 121 running a server application in network 2. As in Figure 1, the client application running on client 112 can still address the server application running on server 111. If enabled to allow connections from inside to outside, the firewall 13 will also allow the client application running on client 112 to connect to the server application running on server 121 outside the firewall 13. The common software package called SOCKS mentioned above enables firewalls to make connections from inside to outside as shown in Figure 2.

Figure 3 again shows two networks but this time the second network 14 is Company B's private network which is behind a second firewall 15. Thus, firewall 15 is designed to protect Company B's computer resources from malicious activity originating from outside firewall 15. In this illustration, a client application running on a client 142 behind firewall 15 may attempt to address the server application running on server 111 behind firewall 13 via the Internet 12. However, while firewall 15 may have the SOCKS capability to allow client application running on client 142 to connect outside the firewall 15, firewall 13 prevents the connection to the server application running on server 111.

Often, an employee inside an organization wants to allow an "outside" client application to address an "inside" server; e.g., to allow the client application running on client 142 to address the server application running on server 111 in Figure 3. In this case, the employee trusts the outside client application and wishes to bypass the controls put in place on their company's firewall that prevent the trusted outside client from addressing the inside server. This invention provides a solution for this situation.

The invention will be described, without loss of generality, in terms of an implementation in the X Windows System. The X Windows System is a standardized set of display-handling routines, developed at MIT for UNIX workstations, that allow the creation of hardware-independent graphical user interfaces (GUIs). In the example described first, two firewalls are addressed. The initial implementation builds on the SOCKS package which enables SOCKS-aware programs inside a SOCKS gateway to connect to servers outside the SOCKS gateway.

Figure 4 shows the three types of proxies used to construct a secure tunnel and their placement in the network configuration according to the present invention. Network 21, Company A's private network or intranet, is protected by firewall 23, and network 22, Company B's private network or intranet, is protected by firewall 25. Behind firewall 23 is an X-server 211, part of Company A's private network, and behind firewall 25 is an X-client 222, part of Company B's private network. Both firewalls 23 and 25 have SOCKS capability to allow "inside" clients to connect to "outside" servers. The X-client 222 has within its addressable domain behind Company B's firewall 25 a client end proxy 223 that has the ability to listen for X protocol. The client end proxy 223 appears as a local X-server to the X-client 222, so no modifications are needed to the X-client 222.

A similar situation exists behind Company A's firewall 23 where a server end proxy 213 exists within the addressable domain of the X-server 211. The server end proxy 213 is able to connect to the X-server 211 just as a real X-client would. The server end proxy 213 appears as a local X-client to the X-server 211 so, again, no modifications are needed to the X-server 211.

A middle proxy 26 is started first, as the end proxies will initiate connections to the middle proxy. The client end proxy 223 and the server end proxy 213 make use of existing capability (e.g., SOCKS) to make requests through a firewall from the inside to the outside. Since the middle proxy 26 is mutually addressable by both end proxies (using SOCKS on each firewall), a complete end-to-end connection between the X-client 222 and the X-server 211 can be established through the middle proxy 26.

The middle proxy 26, which appears as a server to both the client end proxy 223 and the server end proxy 213, is a key feature of the invention. As such, both the client end proxy 223 and the server end proxy 213 can address the middle proxy 26 through their respective firewalls 25 and 23. For cascaded or multiple middle proxies, the middle proxies may actually address other middle proxies as opposed to being addressed by end proxies. The initial connection is made using the standard TCP/IP connection mechanism. Each established connection, no matter which program initiated it, is a TCP/IP connection and is therefore duplex. This invention provides a Lightweight Secure Tunnelling Protocol (LSTP) which is used on top of TCP/IP to provide for

proper sequencing of tunnel management events. LSTP is "spoken" between the client end, server end and middle proxies not just during tunnel construction, but through out the entire tunnel lifetime.

The triggers for the end proxies 213 and 223 to initiate a connection to the middle proxy 26 is manually controlled by someone who has access to the computer where the end proxies 213 and 223 are running. The end proxies 213 and 223 can establish a connection to the middle proxy 26 anytime after the middle proxy is started. The middle proxy 26 will receive and store the setup information sent to it by the first connecting end proxy.

When the middle proxy has two matching connections, one from a client end proxy 223 and one from a server end proxy 213, the middle proxy 26 will join the two connections and act like a transparent pipe, effectively establishing a connection between the two end proxies. From this time forward, the middle proxy 26 is in a pass through mode, and one end proxy initiates a security handshake with the other end proxy to secure the tunnel.

The X-client 222 can now initiate a connection to and passes data to the client end proxy 223 just as if it were connected directly to the X-server 211. The initial data from X-client 222 causes LSTP messages to flow through the tunnel established by the two end proxies 223 and 213 and the middle proxy 26 which then causes server end proxy 213 to initiate a connection to X-server 211. The data from X-client 222 is then passed through the tunnel and presented to the X-server 211. Neither the X-client 222 nor the X-server 211 have any indication that they are not talking directly to each other. Data flows in both directions; from the X-server 211 to the X-client 222 and from the X-client 222 to the X-server 211. At this point, additional clients could connect to the client proxy and use the same or request a new tunnel connection.

To summarize, the server-side end proxy can connect to the inside X Windows System server and the outside middle proxy, and the X Windows System client can connect to the client-side end proxy which can then connect to the outside middle proxy for the X-client. Due to the fact that an established connection is duplex in nature, and due to transitive closure, the X Windows System client can address the X Windows System server as if there were no firewall (i.e., as if they were on the same

addressable network). Those skilled in the art will recognize that the functionality of the end proxies can be increased to allow for other protocols and services. For example, one end proxy could provide both client and server end proxy functionality.

Figure 5 is a data flow diagram illustrating the interaction between the client, middle and server proxies. The process assumes that the middle proxy has been started and it is waiting for the first connection. The client end proxy is started and opens a connection to the middle proxy and sends client setup information to the middle proxy. "Setup information" is a general term describing two pieces of the LSTP protocol. The middle proxy stores the end proxy setup information and then waits for the second connection. The server end proxy is started and opens a connection to the middle proxy, and the server end proxy sends end proxy setup information to the middle proxy. The middle proxy pairs the connections and transmits server and middle proxy setup information to the client end proxy and client and middle proxy setup information to the server end proxy.

At this point in the process, the middle proxy ceases any active role in the connection and acts as a pass through between the client end and server end proxies. Once the connection has been established, either one of the end proxies can initiate a security handshake. An algorithm in each end proxy uses the setup information to decide which end proxy initiates the security handshake. In Figure 5, the client end proxy is shown as transmitting a security handshake that is passed to the server end proxy. The server end proxy responds with a security handshake that is passed to the client end proxy. When this security protocol has been accomplished, additional setup information is re-transmitted over a secure line to complete the tunnel construction. Those skilled in the art will recognize that an alternative sequence of events could be used to establish end to end security over the tunnel. With the connection between the client application and the server application completed, and data can securely pass in both directions between the two using a protocol such as the Lightweight Secure Tunnelling Protocol (LSTP) described below. As a result, the client and server applications have effectively had their addressability extended.

The server and client proxies 213 and 223 handle (1) authentication, encryption, and integrity, (2) firewall pass through, and (3) data compression. The middle proxy 26 acts as a two way pipe. The

server end proxy 213 appears as an X client to the X server 211, while the client end proxy 223 appears as an X server to the X client 222. The server and client end proxies usually reside on the same machine as the X server and X client, respectively.

With this general overview, there are several implementation decisions which were made to implement the secure tunnel between the two networks 21 and 22. First, in the example illustrated, X Windows System clients and servers were used on each tunnel end and, as such, the end proxies are customized to listen for and respond to X protocols. Second, the Secure Sockets Layer (SSL) was chosen as the security protocol to secure the tunnel. SSL provides for data integrity, data privacy, and authenticity of the originating parties. Third, SOCKS was chosen as a mechanism to allow proxies to establish connections from inside the firewall to outside the firewall. Fourth, the Lightweight Secure Tunnelling Protocol (LSTP) was developed along with the tunnel to provide a means for formalizing tunnel construction, management, data flow control, and tunnel destruction.

The Lightweight Secure Tunnelling Protocol (LSTP) according to the invention is the protocol used between the client proxy 223 and the middle proxy 26 and between the server proxy 213 and the middle proxy 26 shown in Figure 4. In the preferred embodiment, LSTP includes the following meanings of and sequencing rules for requests and responses used for transferring data between and synchronizing the states of the proxies:

COMMONUNIQUE_INFO - This information allows two end proxies connect at different times to the same middle proxy. The middle proxy knows that these two end proxies should be paired together because they both provided the same common information. The unique information could be used to identify each end proxy user.

TOPOLOGY_EXCHANGE - This is information that describes the topology of the tunnel. Middle proxies append its topology (e.g., name, address, etc.) information to any TOPOLOGY_EXCHANGE it receives and forwards the TOPOLOGY_EXCHANGE downstream to the end proxy. This provides each end proxy with a map of which proxies are participating in the tunnel.

PROPERTY_EXCHANGE - This mechanism allows for end proxies to exchange information about themselves.

CONNECTION_REQUEST - This request allows one end proxy to notify the other end proxy that a client application is requesting tunnel resources to be allocated for use by the client application. Requested resources may include "multiplexed" channels on an existing tunnel connection or new tunnel connections in addition to established tunnel connections.

CONNECTION_ACK and **CONNECTION_NACK** - These responses allow the proxy receiving a CONNECTION_REQUEST to either accept or deny the request for tunnel resources.

SERVICE_BEGIN_REQUEST - This request allows an end proxy to notify the other end proxy that an application is beginning to send data and therefore use the tunnel resources that have been requested and/or allocated.

SERVICE_BEGIN_ACK and **SERVICE_BEGIN_NACK** - These responses allow an end proxy to accept or deny an application's request to begin using resources that have been allocated.

SERVICE_DATA - This message is used to send application data between two end proxies. Each client/server application pair has a unique identifier included in its SERVICE_DATA message to allow multiple applications to multiplex their data over one TCP/IP connection.

SERVICE_DATA_PAUSE - This message allows an end proxy to tell the other end proxy to stop sending application data.

SERVICE_DATA_RESUME - This message allows an end proxy to tell the other end proxy to resume sending application data.

SERVICE_FREE_REQUEST -This request allows an end proxy to notify the other end proxy that an application is done and tunnel resources can be freed.

SHUTDOWN - This allows an end proxy to shut down the tunnel gracefully by notifying the other end proxy.

ERROR - This message allows an end proxy to exchange error information.

The LSTP is summarized in Figure 6. Note that the first three messages are used to manage tunnel setup and administration. Specifically, the setup information is comprised of varying combinations of COMMONUNIQUE_INFO and TOPOLOGY_EXCHANGE LSTP messages and is used to manage tunnel connections. The next six messages are used to manage resources of an existing tunnel as required by applications using the tunnel. The next message, SERVICE_DATA, is used to transport application data between end proxies. The next two messages are used to manage application data, that is, flow control. The next three messages are used to manage clean up of tunnel resources no longer needed by an

application. Finally, the last message is used to manage error conditions.

This Lightweight Secure Tunnelling Protocol (LSTP) was developed to facilitate tunnel resource management and life cycle. Those skilled in the art will recognize that another protocol encompassing similar features and functionality could be created to accomplish the same goal.

The end proxy flow diagram is shown in Figure 7. The process begins by connecting to a middle proxy in function block 701. The end proxy then sends its COMMONUNIQUE_INFO and TOPOLOGY_EXCHAGE setup information to the middle proxy in function block 702. Next, the end proxy receives other proxies COMMONUNIQUE_INFO and TOPOLOGY_EXCHANGE set information from the middle proxy in function block 703. A master end proxy is chosen based on the TOPOLOGY_EXCHANGE setup information in function block 704. If this proxy is the master end proxy as determined in decision block 705, then a security handshake is initiated in function block 706; otherwise, the end proxy waits for the security handshake in function block 707. Once the security handshake is complete in function block 708, the end proxy resends the COMMONUNIQUE_INFO and TOPOLOGY_EXCHANGE setup information over the secured connection in function block 709. Then, in function block 710, the proxy again receives the COMMONUNIQUE_INFO and TOPOLOGY_EXCHANGE setup information over the secured connection. If the end proxy is a client end proxy, as determined in decision block 711, the proxy waits for the local client application to connect in function block 712. When the local client application is connected in function block 713, the connection is setup and managed using the Lightweight Secure Tunnel Protocol (LSTP) in function block 714. If, on the other hand, the proxy is a server end proxy as determined in decision block 711, the proxy waits for the other end proxy to request a connection in function block 715. When the CONNECTION_REQUEST message is received from the other end proxy in function block 716, the connection is setup and managed using the Lightweight Secure Tunnel Protocol (LSTP) in function block 714.

The middle proxy flow diagram is shown in Figure 8. The process begins by checking in decision block 801 whether there is a new connection from a neighbouring proxy. If so, the new connection is accepted in function block 802, and then a determination is made in decision block 803 as to whether a matching COMMONUNIQUE_INFO message is stored from a previous connection. If not, the COMMONUNIQUE_INFO and

TOPOLOGY_EXCHANGE messages are stored at the middle proxy in function block 804 and the process returns to decision block 801 to await a new connection. If upon receiving a new connection, the COMMONUNIQUE_INFO received matches the previously stored COMMONUNIQUE_INFO as determined in decision block 803, the two connections are paired to establish a path between the two neighbouring proxies in function block 805. The COMMONUNIQUE_INFO that was just matched is removed from storage in function block 806. The COMMONUNIQUE_INFO and the TOPOLOGY_EXCHANGE setup information are exchanged between the two newly matched neighbouring proxies in function block 807, and a return is made to decision block 801. Now if a message is received which is not a new connection from a neighbouring proxy, a test is made in decision block 808 to determine if any existing connection pairs with incoming data are waiting to be serviced. If not, a return is made to decision block 801; otherwise, the middle proxy acts as a pass through in function block 809. That is, the middle proxy receives incoming data from one connection and sends the data out on the other connection in the pair of connected end proxies.

A single middle proxy has been shown to simplify explanation; however, multiple middle proxies can be cascaded, allowing a single tunnel to be constructed across multiple firewalls. In this case, some of the middle proxies are configured to establish a connection with neighbouring middle proxies instead of waiting for a second incoming connection. An alternative embodiment addresses the one firewall cases and is shown in Figure 9. In this case, Company A's private network or intranet 21 includes a X-server 211 and a server end proxy 213 behind the firewall 23. An X-client 27 seeks to address an application running on the X-server 211. A combined client end and middle proxy 28 is used to facilitate this connection. In a similar way, Figure 9 can be envisioned with the X-client and X-server roles reversed.

The solution according to this alternative embodiment of the invention uses two programs, one which acts as a proxy for the X Windows System client and the other which acts as a proxy for the X Windows System server. The client-side proxy runs on the outside network (i.e., the Internet) and is therefore addressable by the X Windows System client. The outside client-side proxy is also addressable by the inside server-side proxy through the firewall, since most firewalls use the SOCKS package to provide a gateway for inside SOCKS-aware programs to

address, and thus connect to, outside services. The process is substantially as described above.

A further enhancement enables additional SOCKS-aware versions of such Internet programs like FTP, TELNET, HTTP, and SMTP to navigate one or more firewalls through the secure tunnel, as shown in Figure 10. This improvement adds the functionality of a SOCKS server to the entire tunnel, so that existing SOCKS-aware TCP/IP clients can communicate with servers on the other end of the tunnel, treating the tunnel itself as a single firewall, even though the tunnel may itself be navigating two or more firewalls. After the middle proxy 26 begins to act as a pass through, LSTP is used between the server end proxy 223 and the client end proxy 213. The middle proxy 26 and the two end proxies 213 and 223 constitute a SOCKS server 261 in this embodiment. The two end proxies need to be customized to properly listen for and communicate with SOCKS-aware client applications.

There are many existing clients that are SOCKified like RTELNET, RFTP, RHTTP, etc. (where the "R" prefix usually indicates that the client is SOCKified). These clients expect to connect to a SOCKS server, which is typically on the firewall, and therefore start by sending SOCKS protocol to the SOCKS server and expect the SOCKS server to respond.

By adding SOCKS server capability to the tunnel, the entire tunnel will do the job of a SOCKS server. So instead of using RTELNET to connect to the firewall, a user could use RTELNET to connect to the SOCKS enabled tunnel and travers as many firewalls as that tunnel instance does. Another way to think of the procedure is adding one protocol (i.e., SOCKS) to the tunnel's functionality and gaining an entire suite of protocols like TELNET, FTP, HTTP, etc. Without SOCKS, it would be necessary to modify the tunnel to understand and respond to TELNET, FTP, HTTP, etc. In addition, commercially available products that allow non-SOCKS-aware clients to make requests from SOCKS servers could be used to allow any client application access to SOCKS-aware end proxies.

The invention has been described as running on UNIX workstations. That is, the server, the client, the end proxies, and the middle proxy are all implemented on UNIX workstations. However, there is no reason why the proxies, for example, could not be run on a personal computer (PC) or main frame computer, depending on a specific application and the resources available. It is just a matter of porting code from a UNIX

base to another platform. In general, an end proxy, middle proxy, and another end proxy could make up a tunnel where each proxy is running on a different hardware/software platform. The end and middle proxies both place relatively low demands on the resources of the computer they are running on.

CLAIMS

1. A packet switched network communications system comprising:

a first network including at least one server running a server application;

a second network including at least one client running a client application;

a first firewall guarding computer resources of one of the first and second networks and including a software application that enables the first firewall to make connections from inside to outside the first firewall;

a server end proxy and a server application that are mutually addressable;

a client end proxy and a client application that are mutually addressable; and

a middle proxy outside the first firewall and in an untrusted network between the first and second networks, the server end proxy and the client end proxy each making connections to the middle proxy through the first firewall and the middle proxy connecting the connections from the server end proxy and the client end proxy to establish a pass through communication tunnel between the client and the server.

2. The packet switched network communications system recited in claim 1 further comprising a second firewall guarding computer resources of the other one of the second and first networks and including a software application that enables the second firewall to make connections from inside to outside the second firewall.

3. The packet switched network communications system recited in claim 2 wherein the server end proxy, the client end proxy and the middle proxy constitute a tunnel having SOCKS server capability, the entire tunnel performing the job of a SOCKS server.

4. In a packet switched network communications system including a first network including at least one server running a server application, a second network including at least one client running a client application, a first firewall guarding computer resources of one of the first and second networks and including a software application that enables the first firewall to make connections from inside to outside the first firewall, a server end proxy addressable by the server application, a client end proxy addressable by the client application,

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